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(54) Spark plug

(57) The size of a tool engagement portion (1e) of a metallic shell (1) of a spark plug is reduced such that |A - E| is not greater than 1.5 mm, where A is an outside dimension of the tool engagement portion (1e), and E is an effective diameter of a male-threaded portion (7) of the metallic shell (1). Also, the effective diameter E of the male-threaded portion (7) of the metallic shell (1) and the diameter D_2 of an intermediate-bore portion (40a) of the metallic shell (1) are determined such that the relationship $0.4 \leq (D_2/E)^2 \leq 0.6$ is satisfied. Therefore, even when the outside diameter of the insulator (2) decreases in association with a reduction in the size of the tool engagement portion (1e), the wall thickness of the male-threaded portion (7) of the metallic shell (1) falls within an appropriate range. Thus, during forging of the metallic shell (1), a forging punch is less susceptible to breakage and is less likely to cause a working defect.

FIG. 1A FIG. 1B

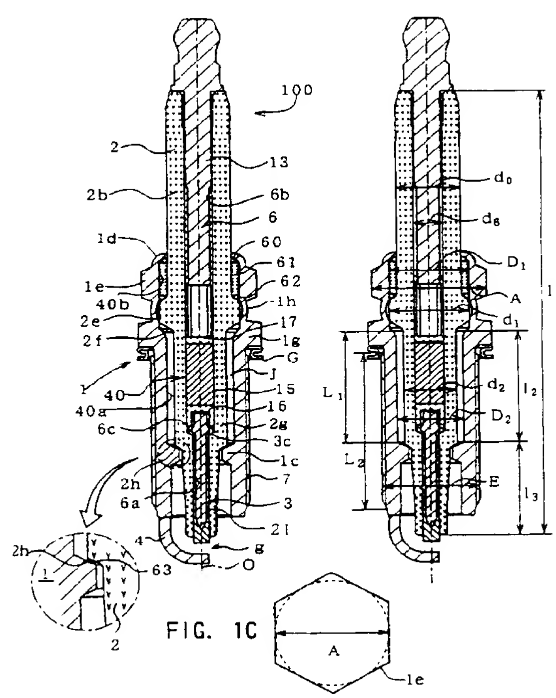

FIG. 1C

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Description

[0001] The present invention relates to a spark plug used for ignition in an internal combustion engine.

[0002] FIG. 9 shows a conventional spark plug 300 used for ignition in an internal combustion engine, such as an automobile gasoline engine. The spark plug 300 is mounted on a cylinder head SH of an engine by means of a male-threaded portion 301a formed on an outer circumferential surface of a metallic shell 301. When the spark plug 300 is mounted on the cylinder head SH, a spark discharge gap g defined by a ground electrode 304 and a center electrode 303 is positioned within a combustion chamber BR and is adapted to ignite a fuel-air mixture. A hexagonal portion 305 (tool engagement portion) is formed on an outer circumferential surface of the metallic shell 301 and is adapted to tighten the male-threaded portion 301a through engagement with a tightening tool. The metallic shell 301 assumes a substantially cylindrical shape having a bore 306 for reception of an insulator 302 and is conventionally manufactured through cold plastic working combined with machining. In many spark plugs, in order to improve manufacturing efficiency, a schematic profile and the bore 306 are formed through die forging, and a final profile including the male-threaded portion 301a is finished through machining. Since the metallic shell 301 has a thin-walled portion, the dimensions of the metallic shell 301 must be designed in consideration of a material flow during die forging; otherwise, a working defect is likely to occur.

[0003] With a recent tendency toward complication of engine head structure, space allocated around a valve for installation of the spark plug 300 is decreasing. Thus, the hexagonal portion 305 is required to be reduced in size so as to increase space for use on the head side. However, reducing the size of the hexagonal portion 305 involves the following problems.

(1) In order to prevent an excessive reduction in the wall thickness of the hexagonal portion 305 in association with a reduction in the size of the hexagonal portion 305, a diameter D_1 of a portion (hereinafter referred to as a major-bore portion) 306a of the shell bore 306 corresponding to the hexagonal portion 305 must be reduced. Also, the outside diameter of the insulator 302 must be reduced accordingly. However, when a diameter D_2 of a portion (hereinafter referred to as an intermediate-bore portion) of the shell bore 306 corresponding to the male-threaded portion 301a is reduced, a forging punch used to form the intermediate-bore portion 306b through forging becomes excessively thin and thus may be damaged or may cause a working defect when a large working load is imposed thereon. This problem arises particularly in the case when the male-threaded portion 301a has a long screw reach.

(2) A portion of the insulator 302 which is positioned within the major-bore portion 306a is formed into a flange portion 302e. When the metallic shell 306 is caulked onto the insulator 302, the flange portion 302e bears a caulking force. A metallic terminal 313 and a center electrode 303 are connected by means of a glass seal portion 315. In the step of forming the glass seal portion 315, the flange portion 302e bears an associated pressing force. Specifically, the center electrode 303, a material powder of the glass seal portion 315, and the metallic terminal 313 are disposed within a through-hole formed in the insulator 302. The thus-prepared insulator 302 is inserted into a bore formed in a seat die such that the flange portion 302e rests on an inner seat portion formed on the wall of the bore. In this state, the entire insulator 302 is heated to a temperature equal to or higher than a glass softening point, and the metallic terminal 313 is pressed axially inward so as to press the material powder in combination with the center electrode 303, thereby forming the glass seal portion 315. During this pressing work, the flange portion 302e bears a pressing force.

If the outside diameter of the insulator 302 is rendered excessively small in order to meet the demand described above in (1), the manufacture of the insulator 302 becomes very difficult. Therefore, there is a certain limit to a reduction in the outside diameter of the insulator 302. As the size of the hexagonal portion 305 is reduced, the diameter D_1 of the major-bore portion 306a is reduced accordingly. Thus, the diameter of the flange portion 302e, which is accommodated within the major-bore portion 306a, is also reduced accordingly. As a result of a reduction in the size of the hexagonal portion 305, the diameter of the flange portion 302e must be reduced to a relatively large extent, whereas there is a certain limit to a reduction in the diameter of a portion of the insulator 302 other than the flange portion 302e (for example, a portion of the insulator 302 positioned within the intermediate-bore portion 306b; hereinafter referred to as an intermediate-trunk portion 302a). As a result, the amount of a projection of the flange portion 302e decreases, causing, for example, a decrease in the area of contact between the flange portion 302e and the seat portion of the seat die used in the step of forming the glass seal portion 315. A resultant load concentration is likely to cause breakage of the seat die or galling of the insulator 302 and the seat die.

(3) If the diameter of the intermediate-trunk portion 302a of the insulator 302 is reduced in order to meet the demand described above in (2), and also the diameter D_2 of the intermediate-bore portion 306b of the metallic shell 306 is set to a rather large value in order to attain favorable workability in rela-

tion to forging as mentioned above in (1), a gap is likely to be formed between the intermediate-bore portion 306b and the intermediate-trunk portion 302a of the insulator 302. The presence of this gap tends to cause an eccentric disposition of the insulator 302 within the metallic shell 301, potentially causing an impairment in spark plug performance (for example, lateral sparking).

[0004] An object of the present invention is to provide a spark plug capable of increasing the degree of freedom with respect to space around a cylinder head on which the spark plug is mounted, through reduction in the size of a tool engagement portion, such as a hexagonal portion, and capable of implementing one or more of the following:

(1) in spite of a reduction in the size of the tool engagement portion, a metallic shell which can be manufactured efficiently and at high yield;
(2) during formation of a conductive glass seal layer or a resistor by use of a seat die, breakage or galling of the seat die is less likely to occur; and
(3) during incorporation of an insulator into the metallic shell, an eccentric disposition of the insulator within the metallic shell is less likely to occur.

[0005] To achieve the above object, the present invention provides a spark plug comprising a rodlike center electrode; a substantially cylindrical insulator enclosing the center electrode; a substantially cylindrical metallic shell having opened opposite ends and enclosing the insulator; and a ground electrode connected to the metallic shell and defining a spark discharge gap in cooperation with the center electrode.

[0006] A male-threaded portion is formed on a front-side outer circumferential surface of the metallic shell, and a tool engagement portion adapted to tighten the male-threaded portion into a female-threaded hole formed in an internal combustion engine is formed on the outer circumferential surface of the metallic shell on a rear side with respect to the male-threaded portion in such a manner as to be projected circumferentially outward. In the specification, the term "front" refers to a spark discharge gap side with respect to an axial direction of the center electrode, and the term "rear" refers to a side opposite the front side.

[0007] The diameter of a front portion of the insulator is reduced by means of a circumferentially-formed-stepped portion. The stepped portion serves as an insulator-side engagement portion. A shell-side engagement portion is projected inward from a portion of an inner surface of the metallic shell corresponding to the male-threaded portion. The insulator is inserted into the metallic shell through a rear-end opening such that the insulator-side engagement portion is engaged with the shell-side engagement portion to thereby prevent the insulator from slipping through the metallic shell.

[0008] In the spark plug, $|A - E|$ is not greater than 1.5 mm, and $(D_2/E)^2$ ranges from 0.4 to 0.6 inclusive, where A is an outside dimension of the tool engagement portion represented by the diameter of an inscribed circle of a cross-sectional outline of the tool engagement portion, E is the effective diameter of the male-threaded portion, and D_2 is the diameter of a portion of a bore of the metallic shell located on a rear side with respect to the shell-side engagement portion (the portion of the bore is hereinafter referred to as an intermediate-bore portion).

[0009] According to the above-described structure, the outside dimension A of the tool engagement portion (for example, a hexagonal portion) is reduced with respect to the effective diameter E of the male-threaded portion such that $|A - E|$ becomes not greater than 1.5 mm. Thus, the degree of freedom with respect to space around a cylinder head on which the spark plug is mounted can be increased. Even when space available around a valve for installation of the spark plug decreases due to complication of cylinder head structure, the spark plug can be easily mounted on the cylinder head. Although the outside diameter of the insulator decreases in association with a reduction in the size of the tool engagement portion, so long as $0.4 \leq (D_2/E)^2 \leq 0.6$, the wall thickness of the male-threaded portion of the metallic shell falls within an appropriate range. Thus, during forging of the metallic shell, a forging punch is less susceptible to breakage and is less likely to cause a working defect. That is, the problem described previously in (1) is solved, and the metallic shell can be manufactured efficiently and at high yield.

[0010] More specifically, $(D_2/E)^2$ represents the ratio of the cross-sectional area of the intermediate-bore portion having the diameter D_2"$\pi(D_2/2)^2$" to the cross-sectional area of the male-threaded portion having the effective diameter E "$\pi(E/2)^2$." The smaller the value $(D_2/E)^2$ (i.e., the more the effective diameter E of the male-threaded portion increases with respect to the diameter D_2 of the intermediate-bore portion), the greater the wall thickness of the male-threaded portion. When $(D_2/E)^2$ is less than 0.4, the wall thickness of the male-threaded portion becomes excessively large, causing an insufficient diameter of the intermediate-bore portion. As a result, when the intermediate-bore portion is to be formed through cold working, such as forging, a forging punch to be used becomes excessively thin and thus may be damaged or may cause a working defect when a large working load is imposed thereon. When $(D_2/E)^2$ is in excess of 0.6, the wall thickness of the male-threaded portion becomes excessively thin. As a result, formation of the male-threaded portion through cold working becomes difficult, and the formed male-threaded portion suffers insufficient strength. More preferably, $(D_2/E)^2$ ranges from 0.45 to 0.55.

[0011] A flange portion may be formed on the outer circumferential surface of the insulator on the rear side

with respect to the stepped portion. In this case, preferably, d_2/d_1 is not greater than 0.75, where d_1 is the outside diameter of the flange portion, and d_2 is the outside diameter of an intermediate-trunk portion extending between the flange portion and the stepped portion. As mentioned previously in (2), in the case of reducing the outside dimension A of the tool engagement portion such that |A - E| is not greater than 1.5 mm, if the outside diameter of the intermediate-trunk portion becomes excessively small, manufacture of the insulator becomes very difficult. Also, a reduction in the size of the tool engagement portion unavoidably requires a reduction in the outside diameter of the flange portion. In other words, the diameter ratio d_2/d_1 between the intermediate-trunk portion and the flange portion tends to increase. As d_2/d_1 increases, the amount of projection of the flange portion from the outer circumferential surface of the intermediate-trunk portion decreases. As a result, as mentioned previously, the step of forming a glass seal portion is likely to involve breakage of a seat die or galling between the insulator and the seat die. Through employment of a d_2/d_1 of not greater than 0.7, the amount of projection of the flange portion becomes sufficiently large, thereby effectively preventing the above-mentioned problem associated with a reduction in the size of the tool engagement portion; i.e., solving the problem described previously in (2). More preferably, d_2/d_1 is not greater than 0.65. However, d_2/d_1 is excessively small, the intermediate-trunk portion becomes too thin for manufacture of the insulator. Therefore, in order to avoid such a problem, the value d_2/d_1 must be adjusted as adequate.

[0012] As mentioned previously under problem (3), if the diameter of the intermediate-bore portion is set to a rather large value in order to attain favorable workability of the metallic shell while the diameter of the intermediate-trunk portion of the insulator is decreased in association with a reduction in the size of the tool engagement portion, a gap is likely to be formed between the intermediate-bore portion of the metallic shell and the intermediate-trunk portion of the insulator. In the case of formation of such a gap, preferably, an eccentricity preventive portion is provided substantially concentrically with the intermediate-bore portion and the intermediate-trunk portion in such a manner as to partially fill the gap. In the step of incorporating the insulator into the metallic shell, the eccentricity preventive portion restricts lateral movement of the insulator; i.e., an eccentric disposition of the insulator within the metallic shell, thereby solving the problem described previously in(3).

[0013] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1A is a longitudinal sectional view showing a spark plug according to an embodiment of the present invention;

FIG. 1B is a longitudinal sectional view showing a dimensional definition with respect to the spark plug of FIG. 1A;

FIG. 1C is a schematic transverse cross section showing a tool engagement portion of the spark plug of FIG. 1A;

FIG. 2A is a longitudinal sectional view showing a spark plug similar to that of FIG. 1A except that a shell-side eccentricity preventive projection is formed;

FIG. 2B is a longitudinal sectional view showing a dimensional definition with respect to the spark plug of FIG. 2A;

FIG. 2C is an enlarged sectional view showing the shell-side eccentricity preventive projection;

FIG. 3A is a longitudinal sectional view showing a spark plug similar to that of FIG. 1A except that an eccentricity preventive ring is disposed;

FIG. 3B is a longitudinal sectional view showing a dimensional definition with respect to the spark plug of FIG. 3A;

FIG. 3C is a perspective view showing the eccentricity preventive ring;

FIG. 4A is a longitudinal sectional view showing a spark plug similar to that of FIG. 1A except that an insulator-side eccentricity preventive projection is formed;

FIG. 4B is a longitudinal sectional view showing a dimensional definition with respect to the spark plug of FIG. 4A;

FIG. 4C is a perspective view showing the insulator-side eccentricity preventive projection;

FIGS. 5A-5D, and 6 are views showing a glass seal step;

FIG. 7A is a graph showing the test results with respect to example 1;

FIG. 7B is a graph showing the test results with respect to example 2;

FIG, 8 is a table showing the test results with respect to example 3; and

FIG. 9 is a longitudinal sectional view showing a conventional spark plug.

[0014] Referring to FIGS. 1A and 1B, a spark plug 100 includes a metallic shell 1, an insulator 2, a center electrode 3, and a ground electrode 4. The metallic shell 1 assumes a substantially cylindrical shape. The insulator 2 is fitted into the metallic shell 1 such that a tip portion 2i is projected from the metallic shell 1. The center electrode 3 is disposed within the insulator 2 such that a tip portion is projected from the insulator 2. One end of the ground electrode 4 is connected to the metallic shell 1 through, for example, welding. A spark discharge gap g is defined by the ground electrode 4 and the center electrode 3. Hereinafter, the term "front" refers to the side of the spark discharge gap g with respect to the axial direction of the center electrode 3, and the term "rear" refers to a side opposite the front side.

[0015] A through-hole 6 is formed axially in the insulator 2. A metallic terminal 13 is inserted into the through-hole 6 from one end and is fixed therein. Similarly, a center electrode 3 is inserted into the through-hole 6 from the other end and is fixed therein. A resistor is disposed within the through-hole 6 and between the metallic terminal 13 and the center electrode 3. The opposite ends of the resistor 15 are electrically connected to the center electrode 3 and the metallic terminal 13 via conductive glass seal layers 16 and 17, respectively. The resistor 15 is formed from a resistor composition which is obtained by the steps of mixing glass powder and conductive-material powder (and, as needed, ceramic powder other than glass) and sintering the resultant mixture by means of, for example, a hot press. Alternatively, the resistor 15 may be omitted, and the metallic terminal 13 and the center electrode 3 may be integrated by means of a single conductive glass seal layer.

[0016] The insulator 2 is formed from an insulating material, such as alumina or aluminum nitride (AlN). The insulator 2 has a flange portion 2e which is formed in an axially intermediate position in such a manner as to be projected circumferentially outward. The insulator 2 includes a main-body portion 2b, which is located on the rear side with respect to the flange portion 2e and has a diameter smaller than that of the flange portion 2e. The insulator 2 further includes an intermediate-trunk portion 2g—which is located on the front side with respect to the flange portion 2e and has a diameter smaller than that of the flange portion 2e—and a tip portion 2i - which is located on the front side with respect to the intermediate-trunk portion 2g and has a diameter smaller than that of the intermediate-trunk portion 2g. A boundary portion between the flange portion 2e and the intermediate-trunk portion 2g is formed into a stepped portion 2f. The intermediate-trunk portion 2g assumes a substantially cylindrical shape. The outside diameter of the tip portion 2i is reduced toward an end of the tip portion 2i such that the tip portion 2i assumes substantially a truncated cone shape.

[0017] The metallic shell 1 is made of a ferrous material suited for cold working, such as low-carbon steel or carbon steel wires for cold heading and cold forging specified in JIS G 3539, and serves as a housing for the spark plug 100. Carbon steel wires for cold heading and cold forging specified in JIS G 3539 and applicable favorably tote present invention include SWCH8A (C: ≤0.10; Si: ≤0.10; Mn: ≤0.60; Al: ≥0.02; balance: Fe (unit: weight %)); SWCH17K (C: 0.15-0.20; Si: 0.10-0.35; Mn: 0.30-0.60; balance: Fe (unit: weight %)); and SWCH25K (C: 0.22-0.28; Si: 0.10-0.35; Mn: 0.30-0.60; balance: Fe (unit: weight %)).

[0018] A male-threaded portion 7 is formed on the front side, outer circumferential surface of the metallic shell 1 and is adapted to attach the spark plug 100 to an engine block. A ring-shaped gasket G is fitted to a root of the male-threaded portion 7. A flange-shaped gas seal portion 1g is formed on an outer circumferential surface of the metallic shell 1 on the rear side with respect to the male-threaded portion 7 and in such a manner as to be projected circumferentially outward. A thin-walled connection portion 1h is located on the rear side with respect to the gas seal portion 1g. A tool engagement portion 1e is formed on the metallic shell 1 on the rear side with respect to the connection portion 1h and in such a manner as to be projected circumferentially outward. The tool engagement portion 1e is adapted to engage with a tool, such as a spanner or a wrench, in order to tighten the male-threaded portion 7 into a female-threaded hole formed in a cylinder head for attachment of the spark plug 100 to the cylinder head. As shown in FIG. 1C, the tool engagement portion 1e has a substantially hexagonal cross section. The spark plug 100 attached to the cylinder head is used to ignite a fuel-air mixture supplied into a combustion chamber. When the spark plug 100 is attached to the cylinder head as described above, the gasket G is compressed and deformed between the gas seal portion 1g and a circumferential edge portion of the female-threaded hole to thereby seal the female-threaded hole and the male-threaded portion 7 against each other.

[0019] A bore 40 is formed axially in the metallic shell 1 so as to receive the insulator 2. A circumferential projection 1c (shell-side engagement portion) is formed on a portion of the wall surface of the bore 40 corresponding to the male-threaded portion 7 and is located in a frontward intermediate position. A portion of the bore 40 which extends rearward from the projection 1c serves as an intermediate-bore portion 40a for accommodating the intermediate-trunk portion 2g of the insulator 2. The intermediate-bore portion 40a is merged into a major-bore portion 40b having a diameter greater than tat of the intermediate-bore portion 40a via a stepped portion formed at the rear end thereof The major-bore portion 40b accommodates the flange portion 2e.

[0020] The outside diameter of the center electrode 3 is smaller than that of the resistor 15. The through-hole 6 formed in the insulator 2 includes a substantially cylindrical first portion 6a for receiving the center electrode 3 and a substantially cylindrical second portion 6b located on the rear side with respect to the first portion 6a and having a diameter greater than that of the first portion 6a. As shown in FIG. 1A, the metallic terminal 13 and the resistor 15 are accommodated within the second portion 6b, and the center electrode 3 is inserted into the first portion 6a. An electrode fixation projection 3c is formed on a rear end portion of the center electrode 3 in such a manner as to be circumferentially projected outward from the outer circumferential surface of the center electrode 3. The first portion 6a and the second portion 6b are connected within the intermediate-trunk portion 2g. via a tapered or radiused seat surface 6c permitting the electrode fixation projection 3c to rest thereon.

[0021] The insulator 2 has a stepped portion 2h formed between the intermediate-trunk portion 2g and the tip portion 2i. Serving as the insulator-side engagement portion, the stepped portion 2h engages with the projection 1c of the metallic shell 1, or the shell-side engagement portion, via a ring-shaped sheet packing 63. In this manner, the insulator 2 is prevented from axially slipping through the metallic shell 1. In a space defined by the outer surface of the insulator and the inner wall of a rear-end opening portion of the metallic shell 1, a ring-shaped wire packing 62 is fitted to a rear-end face of the flange portion 2e; a filler layer 61, such as talc, is disposed on the rear side with respect to the wire packing 62; and a ring-shaped packing 60 is disposed on the rear side with respect to the filler layer 61. While the insulator 2 fitted into the metallic shell 1 is pressed toward the front side, a rear opening edge of the metallic shell 1 is caulked inward and toward the packing 60, thereby forming a caulked portion 1d and thus fixedly integrating the metallic shell 1 and the insulator 2 into a single unit.

[0022] Next, dimensional conditions of the spark plug 100 will be described. $|A - E|$ is not greater than 1.5 mm, where A is an outside dimension of the tool engagement portion 1e represented by the diameter of an inscribed circle of a cross-sectional outline of the tool engagement portion 1e as shown in FIG. 1C, and E is the effective diameter of the male-threaded portion 7 as shown in FIG. 1B (i.e., the size of the tool engagement portion 1e is reduced such that the difference between the outside dimension A of the tool engagement portion 1e and the effective diameter E of the male-threaded portion 7 is not greater than 1.5 mm). Also, $(D_2/E)^2$ ranges from 0.4 to 0.6 inclusive (preferably $0.45 \leq (D_2/E)^2 \leq 0.55$), where D_2 is the diameter of the intermediate-bore portion 40a of the metallic shell 1. Further, d_2/d_1 is not greater than 0.75 (preferably $0.65 \geq d_2/d_1$), where d_1 is the outside diameter of the flange portion 2e of the insulator 2, and d_2 is the outside diameter of the intermediate-trunk portion 2g of the insulator 2.

[0023] More specifically, dimensions of the spark plug 100 are adjusted to the following ranges (parenthesized values are of a tested spark plug of FIG. 1).

- Overall length of insulator 2, l_1: 45 to 100mm (69 mm)
- Length of intermediate-trunk portion 2g, l_2: 3 to 28 mm (18 mm)
- Length of tip portion 2i, l_3: 3 to 25 mm (14 mm)
- Outside diameter of main-body portion 2b, d0: 5 to 12 mm (9 mm)
- Outside diameter of flange portion 2e, d_1: 6 to 13 mm (11.3 mm)
- Outside diameter of intermediate-trunk portion 2g, d_2: 4.5 to 10 mm (7.3 mm)
- Outside dimension of tool engagement portion 1e, A: 5.5 to 15.5 mm (14 mm)
- Diameter of intermediate-bore portion 40a, D_2: 4.5 to 11 mm (9.5 mm)
- Length of intermediate-bore portion 40a, L_1: 3 to 28 mm (17mm)
- Diameter of major-bore portion 40b, D_1: 6.1 to 13. 5 mm (13.06 mm)
- Effective diameter of male-threaded portion 7, E: 7 to 14 mm (14 mm)
- Screw reach of male-threaded portion 7, L_2: 10 to 27 mm (24.5 mm)

[0024] In manufacture of the metallic shell 1, a material wire as specified in, for example, JIS G 3539 "Carbon Steel Wires for Cold Heading and Cold Forging" is cut into rods, each having a predetermined length. The rod is die-forged so as to assume a rough profile and to form the bore 40 therein. The resulting workpiece undergoes form rolling so as to form the male-threaded portion 7 thereon, followed by finishing work to yield the metallic shell 1.

[0025] Next, the step of attaching the center electrode 3 and the metallic terminal 13 to the insulator 2 and forming the resistor 15 and the conductive glass seal layers 16 and 17 (hereinafter referred to as a glass seal step) will be described briefly. As shown in FIG. 5A, the center electrode 3 is inserted into the first portion 6a of the through-hole 6 formed in the insulator 2. Subsequently, as shown in FIG. 5B, a conductive glass powder H is placed in the through-hole 6. Then, as shown in FIG. 5C, a presser bar 28 is inserted into the through-hole 6 so as to preliminarily compress the powder H, thereby forming a first conductive glass powder layer 26. Next, a resistor composition powder is placed in the through-hole 6 and undergoes preliminary compression in a similar manner, thereby forming a resistor composition powder layer 25. Further, a conductive glass powder is placed in the through-hole 6, followed by similar preliminary compression to thereby form a second conductive glass powder layer 27. As a result, as shown in FIG. 5D, the first conductive glass powder layer 26, the resistor composition powder layer 25, and the second conductive glass powder layer 27 are arranged in layers on the center electrode 3.

[0026] FIG. 6(A) shows an assembly PA of the metallic terminal 13 and the insulator 2, in which the metallic terminal 13 is inserted into the through-hole 6 of the insulator 2. The insulator 2 is inserted into a through-hole Sa formed in a seat die S so that the flange portion 2e rests on an edge portion of the through-hole Sa. The assembly PA is placed in a furnace and is heated to a predetermined temperature of 900°C to 1000°C (an average temperature of the entire assembly PA), which is equal to or higher than a glass softening point. Subsequently, the metallic terminal 13 is pressed further into the through-hole 6 to thereby axially press the layers 26, 25, and 27. As a result, as shown in FIG. 6(B), the layers 26, 25, and 27 are compressed and sintered to thereby become the conductive

glass seal layer 16, the resistor 15, and the conductive glass seal layer 17, respectively. In this glass seal step, the flange portion 2e bears a force of the above pressing work.

[0027] As described previously, dimensional conditions of the present invention yield the following action and effect in the glass seal step. Through reduction of the outside dimension A of the tool engagement portion 1e such that $|A - E|$ becomes not greater than 1.5 mm, the degree of freedom with respect to space around a cylinder head can be increased. Through employment of $0.4 \leq (D_2/E)^2 \leq 0.6$, the wall thickness of the male-threaded portion 7 falls within an appropriate range. Thus, during forging of the metallic shell 1, a forging punch is less susceptible to breakage and is less likely to cause a working defect, so that the metallic shell 1 can be manufactured efficiently and at high yield. Through employment of a d_2/d_1 of not greater than 0.75, the amount of projection of the flange portion 2e becomes sufficiently large, whereby the glass seal step is less likely to involve breakage of the seat die S or galling between the insulator 2 and the seat die S which would otherwise results from load concentration.

[0028] A wall thickness T of the male-threaded portion 7 can be represented by $(E - D_2)/2$. The male-threaded portion 7 may be designed from the viewpoint of the wall thickness T in the following manner. For example, in the case of 7 mm$\leq E \leq$14 mm and 4.5 mm$\leq D_2 \leq$11 mm, 3 mm$\leq (E - D_2) \leq$5 mm is preferred. If $(E - D_2)$ is less than 3 mm, the wall thickness T becomes too thin for formation of the male-threaded portion 7 through cold working. If $(E - D_2)$ is in excess of 5 mm, the wall thickness T becomes excessively large, causing an insufficient diameter D_2 of the intermediate-bore portion 40a. As a result, when the intermediate-bore portion 40a is to be formed through cold working, such as forging, a forging punch to be used becomes excessively thin and thus may be damaged or may cause a working defect when a large working load is imposed thereon. More preferably, $(E - D_2)$ ranges from 3.5 mm to 4.5 mm.

[0029] As the screw reach L_2 of the male-threaded portion 7 increases, the above-mentioned problem is more likely to occur. A lower limit of the ratio of the wall thickness T of the male-threaded portion 7 to the screw reach L_2; i.e., a lower limit of T/L_2 is adjusted so as to impart a sufficient wall thickness to the male-threaded portion 7 in order to prevent difficulty in forming the male-threaded portion 7 through cold working. An upper limit of T/L_2 is adjusted so as to prevent the problem in that, when the intermediate-bore portion 40a is to be formed through cold working, such as forging, a forging punch to be used becomes excessively thin and thus may be damaged or may cause a working defect when a large working load is imposed thereon.

[0030] The amount of projection of the flange portion 2e from the outer circumferential surface of the intermediate-trunk portion 2g is represented by $(d_1 - d_2)$, where d_1 is the outside diameter of the flange portion 2e, and d_2 is the outside diameter of the intermediate-trunk portion 2g. In the case of 6 mm$\leq d_1 \leq$13 mm and 4.5 mm$\leq d_2 \leq$10 mm, 1.5 mm$\leq (d_1 - d_2)$ is preferred. Through employment of $(d_1 - d_2)$ not less than 1.5 mm, the amount of projection of the flange portion 2e becomes sufficiently large, thereby effectively preventing the aforementioned problem which would otherwise arise in association with a reduction in the size of the tool engagement portion 1e. Notably, the radio d_2/d_1 is adjusted as appropriate in order to prevent the problem in that the intermediate-trunk portion 2g becomes too thin for manufacture of the insulator 2. More preferably, $(d_1 - d_2)$ is not less than 2 mm.

[0031] If the diameter D_2 of the intermediate-bore portion 40a is set to a rather large value in order to attain favorable workability of the metallic shell 1; specifically, in order to attain favorable durability of a forging punch while the diameter of the intermediate-trunk portion 2g of the insulator 2 is decreased in association with a reduction in the size of the tool engagement portion 1e, a gap J is likely to be formed between the wall of the intermediate-bore portion 40a and the outer surface of the intermediate-trunk portion 2g. In this case, an eccentricity preventive portion is provided substantially concentrically with the intermediate-bore portion 40a and the intermediate-trunk portion 2g in such a manner as to partially fill the gap J, thereby preventing an eccentric disposition of the insulator 2 within the metallic shell 1. Examples of the eccentricity preventive portion will next be described.

[0032] FIGS. 2A and 2B show a spark plug 110 similar to that of FIGS. 1A and 1B except that a shell-side eccentricity preventive projection is serving as the eccentricity preventive portion is circumferentially formed on the wall of the intermediate-bore portion 40a (the same features as those of FIGS. 1A and 1B are denoted by common reference numerals, and their description is omitted). The shell-side eccentricity preventive projection 1s is formed continuously with a rear edge of the shell-side engagement portion 2h and annularly along the circumferential direction of the intermediate-bore portion 40a. An inner circumferential surface 1s2 of the shell-side eccentricity preventive projection 1s assumes a cylindrical surface corresponding to an outer circumferential surface of the intermediate-trunk portion 2g. As shown in FIG. 2C, the inner circumferential surface 1s2 and the wall surface of the intermediate-bore portion 40a are connected by means of a tapered connection surface 1s1. In the step of incorporating the insulator 2 into the metallic shell 1, the shell-side eccentricity preventive projection 1s restricts lateral movement of the insulator 2, thereby preventing an eccentric disposition of the insulator 2 within the metallic shell 1.

[0033] The shell-side eccentricity preventive projection 1s has a bore diameter D_3 and an axial length Q of the inner circumferential surface. Preferably, the shell-

side eccentricity preventive projection 1s meets the following dimensional conditions: $0.96 \leq d_2/D_3 < 1$, and $Q \geq 1$ mm, where d_2 is the diameter of the intermediate-bore portion 40a. If d_2/D_3 is less than 0.95 or if Q is less than 1 mm, the effect of preventing lateral movement of the insulator 2 becomes insufficient. If d_2/D_3 is in excess of 1, the insertion of the intermediate-trunk portion 2g into the intermediate-bore portion 40a becomes difficult. The ratio d_2/D_3 is preferably 0.97 to 0.98. The length Q is preferably not less than 1.5 mm. If Q/L_1 (where L_1 is the axial length of the intermediate-bore portion 40a including the shell-side eccentricity preventive projection 1s) is in excess of 0.3, a similar result to that in the case where the wall thickness of the male-threaded portion 7 is increased will arise, causing an increased likelihood of breakage of a forging punch. Therefore, Q/L_1 is set to not greater than 0.3, preferably not greater than 0.2. Since a gap between the outer circumferential surface of the flange portion 2e and the wall of the major-bore portion 40b may also cause an eccentric disposition of the insulator 2, preferably, d_1/D_1 is also adjusted to a range of 0.96 to 1.

[0034] FIGS. 3A and 3B show a spark plug 120 similar to that of FIGS. 1A and 1B except that an eccentricity preventive ring 50 serving as the eccentricity preventive portion is disposed around the intermediate-trunk portion 2g of the insulator 2 (the same features as those of FIGS. 1A and 1B are denoted by common reference numerals, and their description is omitted). The eccentricity preventive ring 50 may be formed of, for example plastic, hard rubber, metal, or ceramic. In attachment, the eccentricity preventive ring 50 may be inserted beforehand into the intermediate-bore portion 40a of the metallic shell 1. Then, the insulator 2 may be inserted into the eccentricity preventive ring 50. Alternatively, the eccentricity preventive ring 50 may be press-fitted beforehand to the insulator 2. Then, the thus-prepared insulator 2 may be inserted into the metallic shell 1.

[0035] Basically, the eccentricity preventive ring 50 produces an effect similar to that produced by the shell-side eccentricity preventive projection 1s of the spark plug 110 shown in FIGS. 2A and 2B. In contrast to the employment of the eccentricity preventive projection 1s, the employment of the eccentricity preventive ring 50 does not involve an increase in the wall thickness of the male-threaded portion 7 and is thus advantageous m terms of the workability of the metallic shell 1.

[0036] As shown in FIG. 3C, the eccentricity preventive ring 50 has an outside diameter δ, a bore diameter D_3, and an axial length Q. Preferably, the eccentricity preventive ring 50 meets the following dimensional conditions: $0.96 \leq \delta/D_2 \leq 1$, $0.96 \leq d_2/D_3 \leq 1$, and $Q \geq 1$ mm. If δ/D_2 or d_2/D_3 is less than 0.96 or if Q is less than 1 mm, the effect of preventing lateral movement of the insulator 2 becomes insufficient. If δ/D_2 is in excess of 1, the insertion of the eccentricity preventive ring 50 into the intermediate-bore portion 40a becomes difficult. If d_2/D_3 is in excess of 1, the insertion of the intermediate-trunk portion 2g into the eccentricity preventive ring 50 becomes difficult (however, if the eccentricity preventive ring 50 is elastically deformable, even though at least either δ/D2 or d_2/D_3 is slightly greater than 1, no problem may arise). The ratios δ/D2 and d_2/D_3 are preferably 0.97 to 0.98. The length Q is preferably not less than 2 mm. Similarly, $0.95 \leq F/d \leq 1$, where F is the wall thickness of the eccentricity preventive ring 50, and d is the dimension of the gap J. As mentioned previously, since the disposition of the eccentricity preventive ring 50 has no effect on the workability of the metallic shell 1, Q may be lengthened substantially to the axial length L_1 of the intermediate-bore portion 40a.

[0037] FIGS. 4A and 4B show a spark plug 130 similar to that of FIGS. 1A and 1B except that an insulator-side eccentricity preventive projection 70 serving as the eccentricity preventive portion is disposed on the intermediate-trunk portion 2g of the insulator 2 (the same features as those of FIGS. 1A and 1B are denoted by common reference numerals, and their description is omitted). The insulator-side eccentricity preventive projection 70 is formed of plastic and is integrally fitted to the outer circumferential surface of the insulator 2 so as to assume an annular form as shown in FIG. 4C. After the glass seal step is completed, the insulator-side eccentricity preventive projection 70 may be formed on the outer circumferential surface of the insulator 2 by means of, for example, insert molding.

[0038] The insulator-side eccentricity preventive projection 70 also produces an effect similar to that produced by the shell-side eccentricity preventive projection 1s of the spark plug 110 shown in FIGS. 2A and 2B. The employment of the insulator-side eccentricity preventive projection 70 does not involve an increase in the wall thickness of the male-threaded portion 7 and is thus advantageous in terms of the workability of the metallic shell 1.

[0039] The insulator-side eccentricity preventive projection 70 has an outside diameter δ2 and an axial length Q. Preferably, the insulator-side eccentricity preventive projection 70 meets the following dimensional conditions: $0.96 \leq \delta_2/D_2 \leq 1$, and $Q \geq 1$ mm. If δ_2/D_2 is less than 0.96 or if Q is less than 1 mm, the effect of preventing lateral movement of the insulator 2 becomes insufficient. If δ_2/D_2 is in excess of 1, the insertion of the insulator-side eccentricity preventive projection 70 into the intermediate-bore portion 40a becomes difficult (however, if the insulator-side eccentricity preventive projection 70 is elastically deformable, even though at least either δ_2/D_2 is slightly greater than 1, no problem may arise). The ratio δ_2/D_2 is preferably 0.97 to 0.98. The length Q is preferably not less than 2 mm. Similarly, $0.95 \leq G/d \leq 1$, where G is the height of the insulator-side eccentricity preventive projection 70, and d is the dimension of the gap J. The axial length Q may be lengthened substantially to the axial length L_1 of the

intermediate-bore portion 40a.

EXAMPLES

Example 1:

[0040] The metallic shells 1 of the spark plug shown in FIG. 1 were manufactured by use of SWCH8A specified in JIS G 3539 "Carbon Steel Wires for Cold Heading and Cold Forging" and through cold forging (the male-threaded portion 7 was formed through rolling). Dimensions of the metallic shell 1 were as follows:

- Outside dimension of tool engagement portion 1e, A: 14 mm
- Diameter of intermediate-bore portion 40% D_2: (7) mm to (11) mm
- Length of intermediate-bore portion 40a, L_1: 17 mm
- Diameter of major-bore portion 40b, D_1: 13.06 mm
- Effective diameter of male-threaded portion 7, E: 13.05 mm
- Screw reach of male-threaded portion 7, L_2: 26.5 mm
- $0.3 \leq (D_2/E)^2 \leq 0.7$

[0041] The intermediate-bore portion 40a was formed through cold forging which was performed in 6 stages. A forging punch used in the sixth stage, which has the greatest area reduction rate, was tested for life with respect to various values of $(D_2/E)^2$. The life of the forging punch was evaluated in terms of the number of forging operations until (D_2r - D_2a) became 0.05 mm or greater, where D_2a is a target value of the diameter D_2 of the intermediate-bore portion 40a, and D_2r is an actually obtained value of the diameter D_2. The test results are shown in FIG. 7A (the life of a forging punch is represented by a relative value, while that as measured when (D_2/E^2 is 0.5 is take as 1.0). As seen from FIG. 7A, the forging punch life is elongated when (D_2/E^2 ranges from 0.4 to 0.6.

Example 2:

[0042] The metallic shells 1 of the spark plug shown in FIG. 2 were manufactured by use of SWCH8A specified in JIS G 3539 "Carbon Steel Wires for Cold Heading and Cold Forging" and through cold forging (the male-threaded portion 7 was formed through rolling). Dimensions of the metallic shell 1 were as follows:

- Outside dimension of tool engagement portion 1e, A: 14 mm
- Diameter of intermediate-bore portion 40a, D_2: 9.2 mm
- Length of intermediate-bore portion 40a, L_1: 17 mm
- Diameter of major-bore portion 40b, D_1: 13.06 mm
- Effective diameter of male-threaded portion 7, E: 14 mm
- Screw reach of male-threaded portion 7, L_2: 26.5 mm
- Bore diameter of shell-side eccentricity preventive projection 1s, D_3: 7.5 to 8.6 mm

[0043] The insulators 2 having the following dimensions were manufactured by use of alumina ceramic.

- Overall length of insulator 2, l_1: 69 mm
- Length of intermediate-trunk portion 2g, l_2: 18 mm
- Length of tip portion 2i, l_3: 14 mm
- Outside diameter of main-body portion 2b, d0: 9 mm
- Outside diameter of flange portion 2e, d_1: 11.3 mm
- Outside diameter of intermediate-trunk portion 2g, d_2: 7.3 mm
- d_2/D_3: 0.85 to 0.975

[0044] Through use of the above-manufactured metallic shells 1 and insulators 2, 10 spark plugs shown in FIG. 2 were assembled for each test value of d_2/D_3. The assembled spark plugs were measured for a maximum amount of eccentricity of the insulator 2 with respect to the metallic shell 1. The results are shown in FIG. 7B. As seen from FIG. 7B, the amount of eccentricity decreases considerably at a value d_2/D_3 of not less than 0.96.

Example 3:

[0045] The insulators 2 of the spark plug shown in FIG. 1 were manufactured by use of alumina ceramic so as to assume the following dimensions.

- Overall length of insulator 2, l_1: 69 mm
- Length of intermediate-trunk portion 2g, l_2: 18 mm
- Length of tip portion 2i, l_3: 14 mm
- Outside diameter of main-body portion 2b, d0: 9 mm
- Outside diameter of flange portion 2e, d_1: 7.7 to 12.15 mm
- Outside diameter of intermediate-trunk portion 2g, d_2: 7.3 mm
- d_2/D_3: 0.6 to 0.95

[0046] Through use of the above-manufactured insulators 2 and by use of the methods illustrated in FIGS. 5 and 6, the glass seal step was repeated 2000 times for each test value of d_2/d_1. The evaluation criteria are as follows:

Circle mark: The seat die and the insulator assembly are both free of any anomaly, and galling does not occur.

X mark: A problem, such as the chipping of the insulator or the galling of the seat die, has occurred.

[0047] The results are shown in FIG. 8. As seen

from FIG. 8, glass seal productivity is favorable at a value d_2/d_1 of not greater than 0.75.

[0048] Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the present invention may be practiced otherwise than as specifically described herein.

Claims

1. A spark plug comprising a rodlike center electrode (3), a substantially cylindrical insulator (2) enclosing said center electrode (3), a substantially cylindrical metallic shell (1) having open opposite ends and enclosing said insulator (2), and a ground electrode (4) connected to said metallic shell (1) and defining a spark discharge gap in cooperation with said center electrode (3), in which a male-threaded portion (7) is formed on a front-side outer circumferential surface of said metallic shell (1), and a tool engagement portion (1e) adapted to tighten the male-threaded portion (7) into a female-threaded hole formed in an internal combustion engine is formed on the outer circumferential surface of said metallic shell (1) on a rear side with respect to the male-threaded portion (7) in such a manner as to be projected circumferentially outward; and said insulator (2) has a stepped annular insulator-side engagement portion, upon insertion of said insulator into said metallic shell (1) from the rear side thereof, the insulator-side engagement portion being engaged with an annular shell-side engagement portion projected inward from a portion of an inner surface of said metallic shell (1) corresponding to the male-threaded portion (7), characterized in that

   $|A - E| \leq 1.5$ mm, and $0.4 \leq (D_2/E)^2 \leq 0.6$, where A is an outside dimension of the tool engagement portion (1e) represented by a diameter of an inscribed circle of a cross-sectional outline of the tool engagement portion (1e), E is an effective diameter of the male-threaded portion (7), and D_2 is an inner diameter of an intermediate-bore portion (40a) of said metallic shell (1) located on a rear side with respect to the shell-side engagement portion.

2. A spark plug according to claim 1, further characterized in that 7 mm $\leq E \leq$ 14 mm, 4.5 mm$\leq D_2 \leq$ 11mm, and 1.5 mm$\leq (E-D_2) \leq$ 5.2mm.

3. A spark plug according to claim 1 or 2, further characterized in that a flange portion (2e) is formed on an outer circumferential surface of said insulator (2) on a rear side with respect to the stepped portion, and $d_2/d_1 \leq 0.75$, where d_1 is an outside diameter of the flange portion (2e), and d_2 is an outside diameter of an intermediate-trunk portion (2g) extending between the flange portion (2e) and the stepped portion.

4. A spark plug according to claim 3, further characterized in that 6 mm $\leq d_1 \leq$ 13 mm, 4.5 mm $\leq d_2 \leq$ 10 mm, and 1.5 mm $\leq (d_1 - d_2) \leq$ 8 mm.

5. A spark plug according to claim 3 or 4, further characterized in that a predetermined gap is formed between the intermediate-bore portion (40a) of said metallic shell (1) and the intermediate-trunk portion (2g) of said insulator (2), and an eccentricity preventive portion is provided substantially concentrically with the intermediate-bore portion (40a) and the intermediate-trunk portion (2g) in such a manner as to partially fill the gap and so as to prevent an eccentric disposition of said insulator (2) within said metallic shell (1).

6. A spark plug according to claim 5, further characterized in that a shell-side eccentricity preventive projection (1s) is circumferentially projected from an wall surface of the intermediate-bore portion (40a) so as to serve as the eccentricity preventive portion.

7. A spark plug according to claim 6, further characterized in that $0.96 \leq d_2/D_3 < 1$, and $Q \geq 1$ mm, where D_3 is a bore diameter of the shell-side eccentricity preventive projection (1s), and Q is an axial length of the shell-side eccentricity preventive projection (1s).

8. A spark plug according to claim 5, further characterized in that an eccentricity preventive ring (50) is disposed around the intermediate-trunk portion (2g) of said insulator (2) so as to serve as the eccentricity preventive portion.

9. A spark plug according to claim 8, further characterized in that $0.96 \leq \delta D_2 < 1.1$, $0.96 \leq d_2/D_3 \leq 1$, and $Q \geq 1$ mm, where δ is an outside diameter of the eccentricity preventive ring (50), D_3 is a bore diameter of the eccentricity preventive ring (50), and Q is an axial length of the eccentricity preventive ring (50).

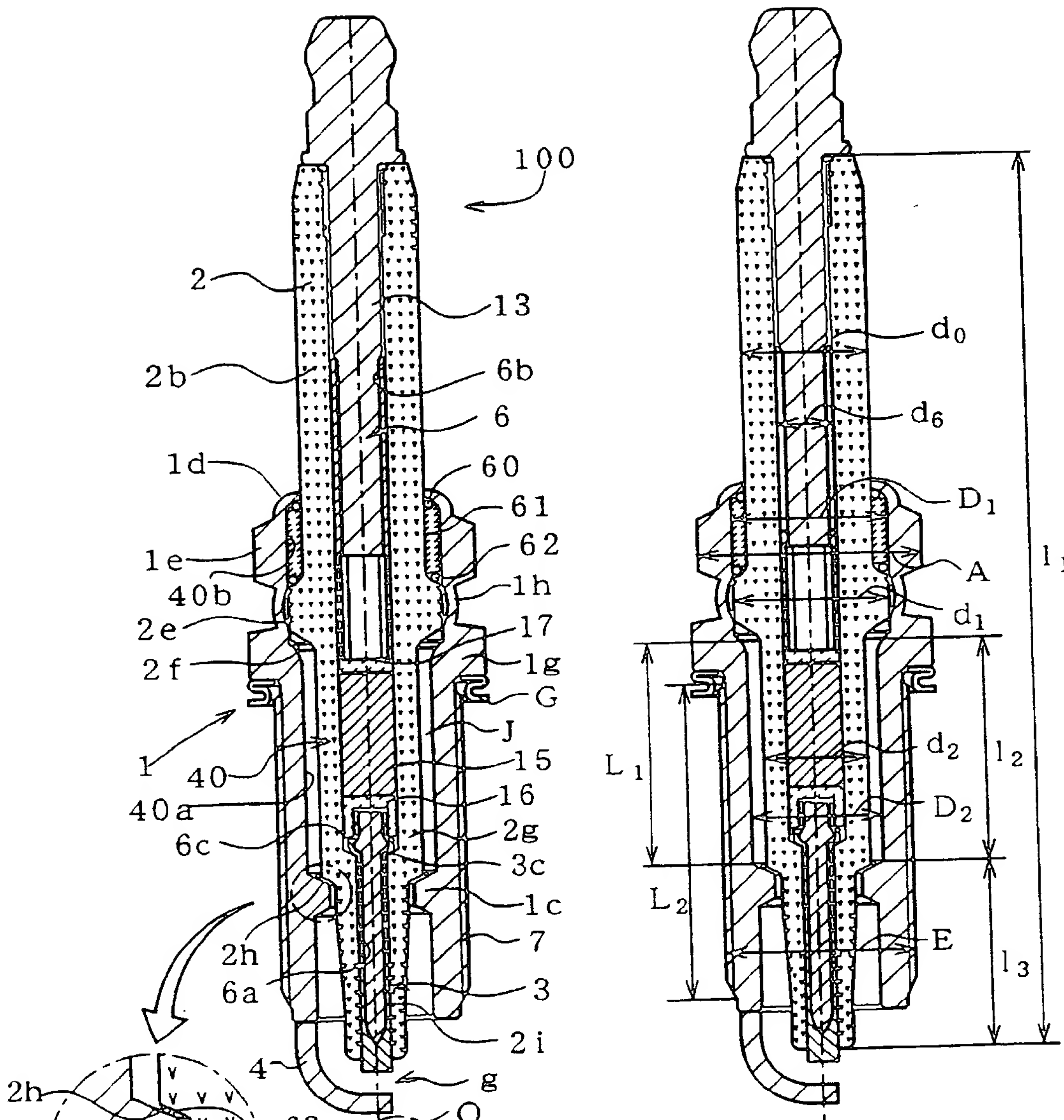
10. A spark plug according to claim 5, further characterized in that an insulator-side eccentricity preventive projection (70) is circumferentially projected from an outer circumferential surface of the intermediate-trunk portion (2g) of said insulator (2) so as to serve as the eccentricity preventive portion.

11. A spark plug according to claim 10, further characterized in that $0.96 \leq \delta_2/D_2 < 1$, and $Q \geq 1$mm,

where δ2 is an outside diameter of the insulator-side eccentricity preventive projection (70), and Q is an axial length of the insulator-side eccentricity preventive projection (70).

FIG. 1A

FIG. 1B



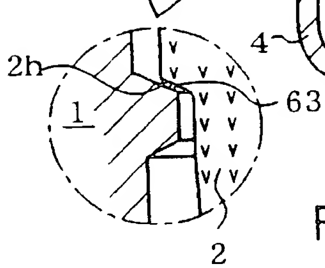


FIG. 1C

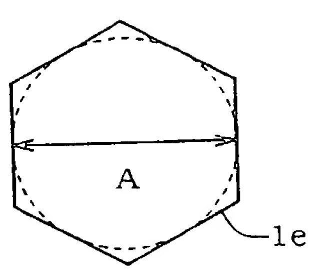


FIG. 2A FIG. 2B

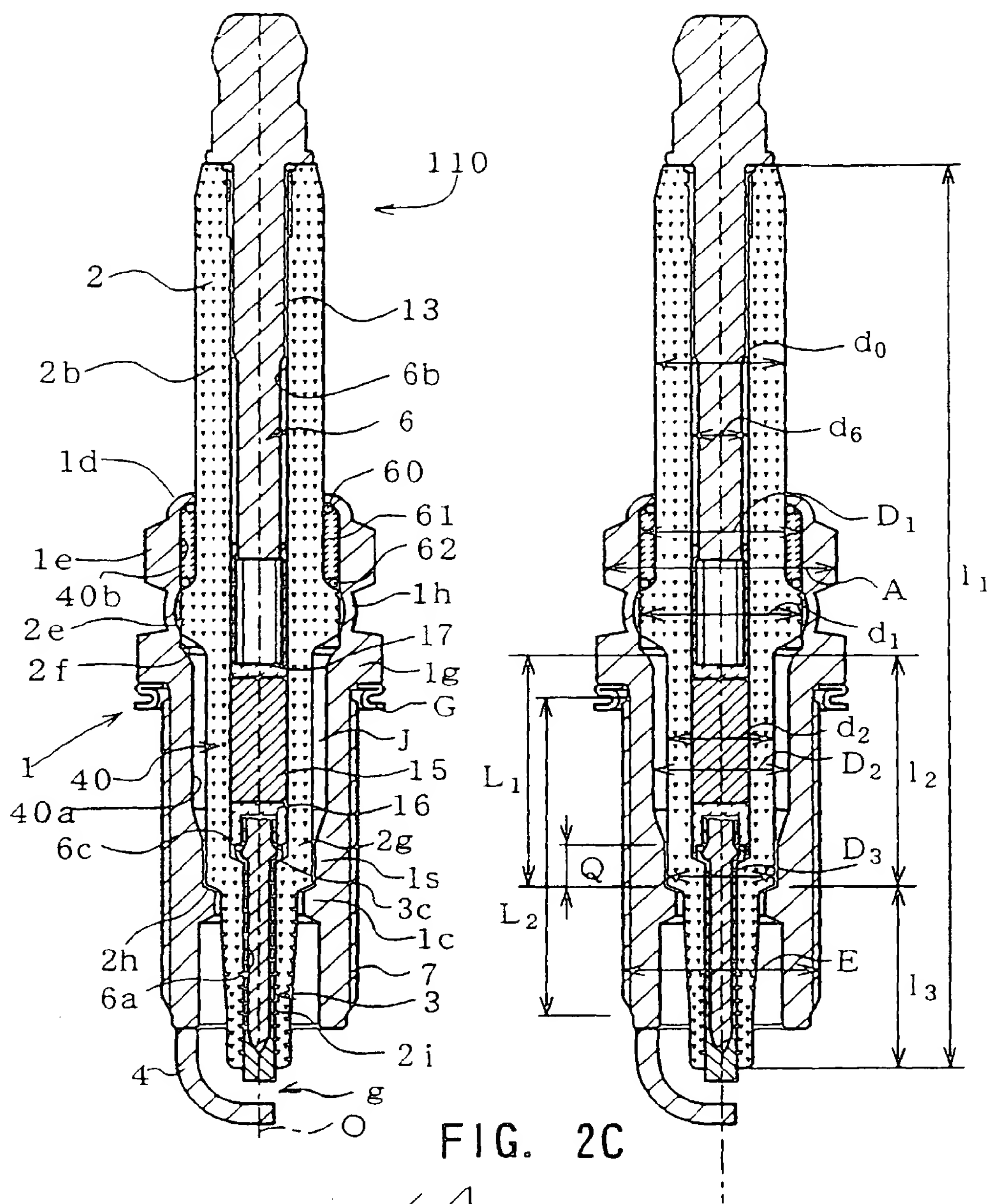


FIG. 2C

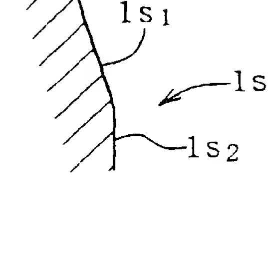


FIG. 3A

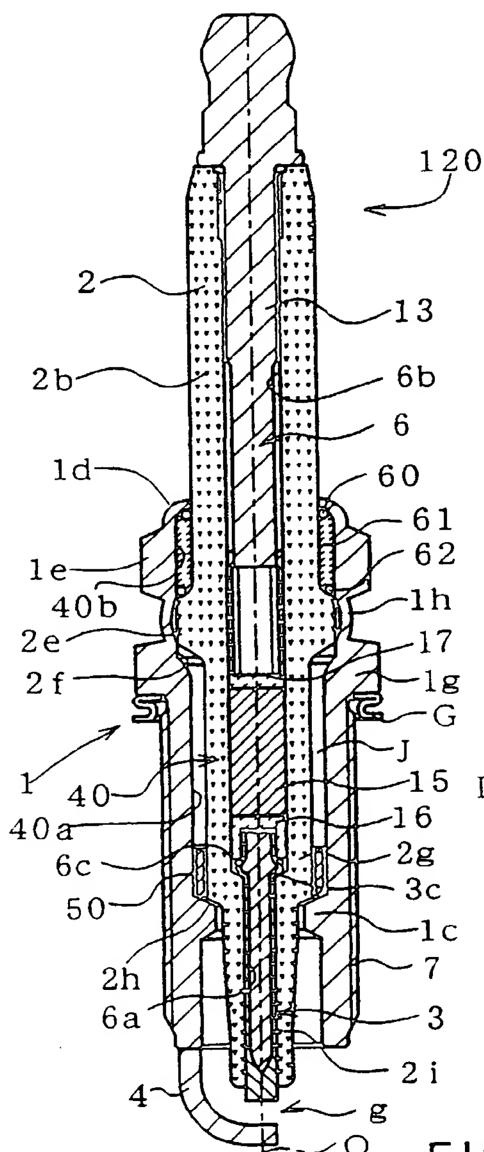


FIG. 3B

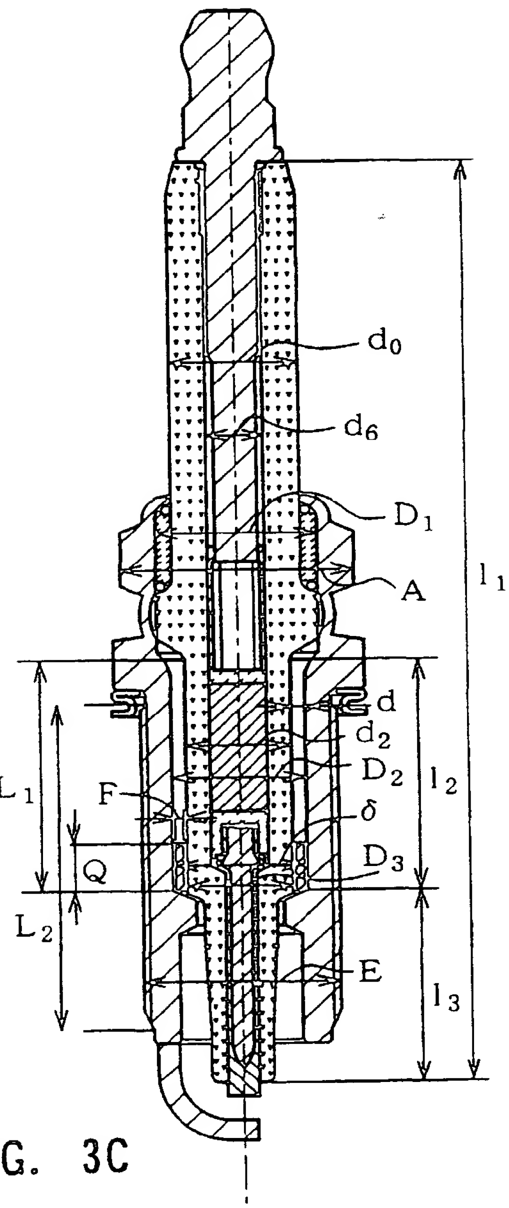


FIG. 3C

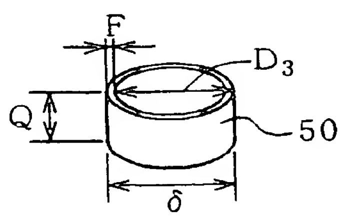


FIG. 4A

FIG. 4B

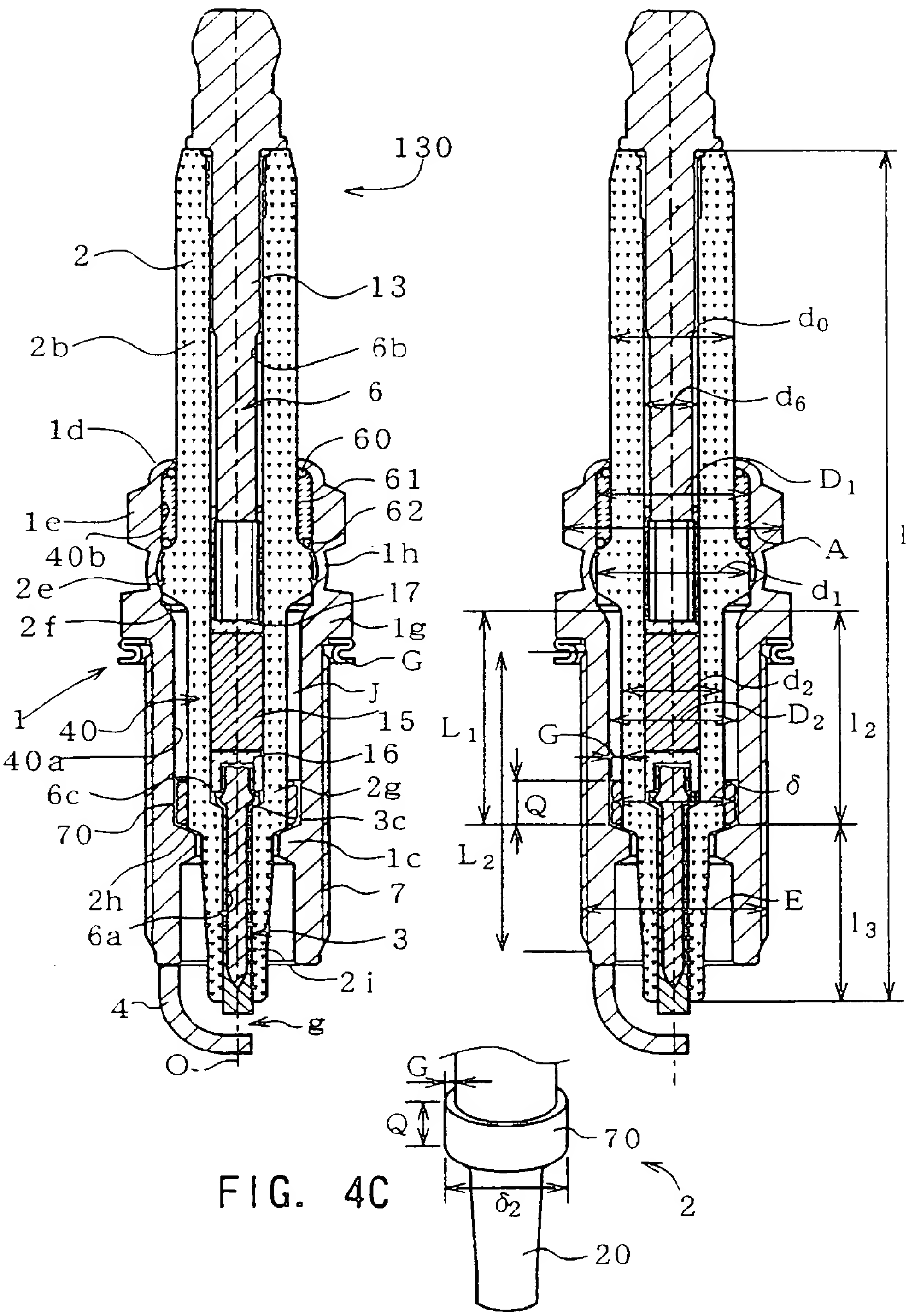


FIG. 4C

FIG. 5A

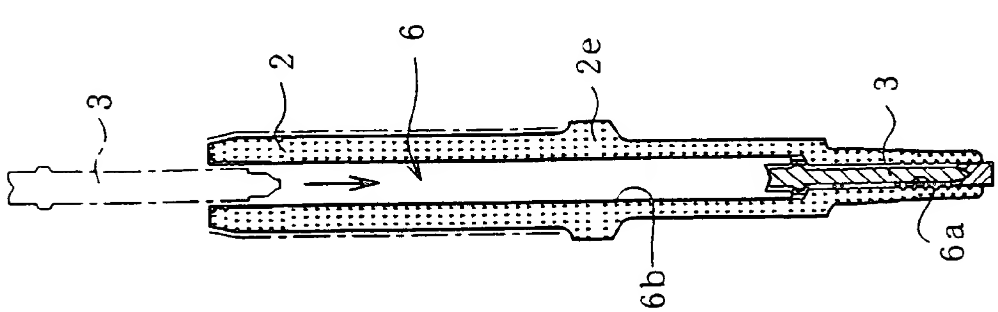


FIG. 5B

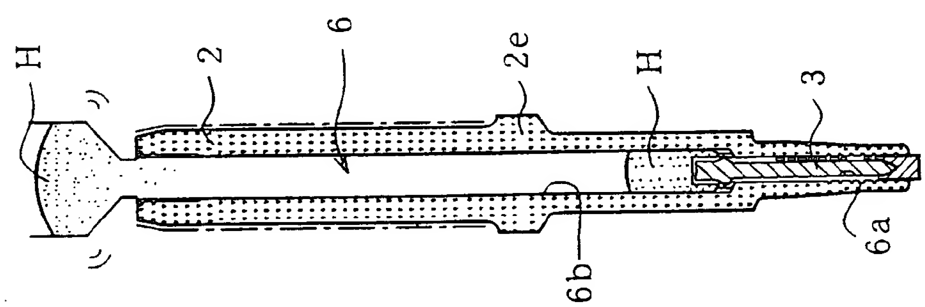


FIG. 5C

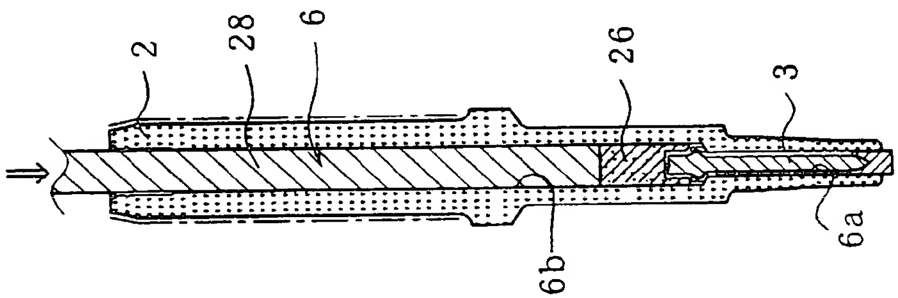


FIG. 5D

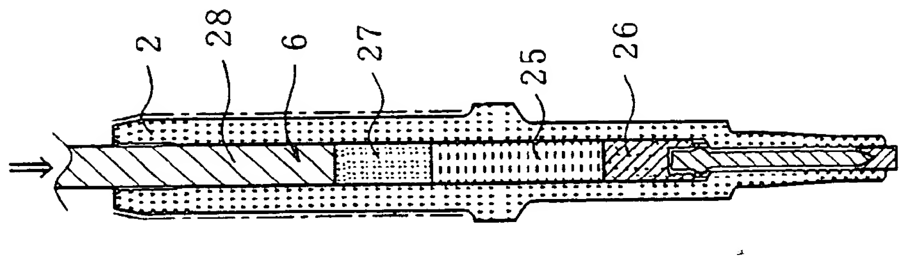


FIG. 6

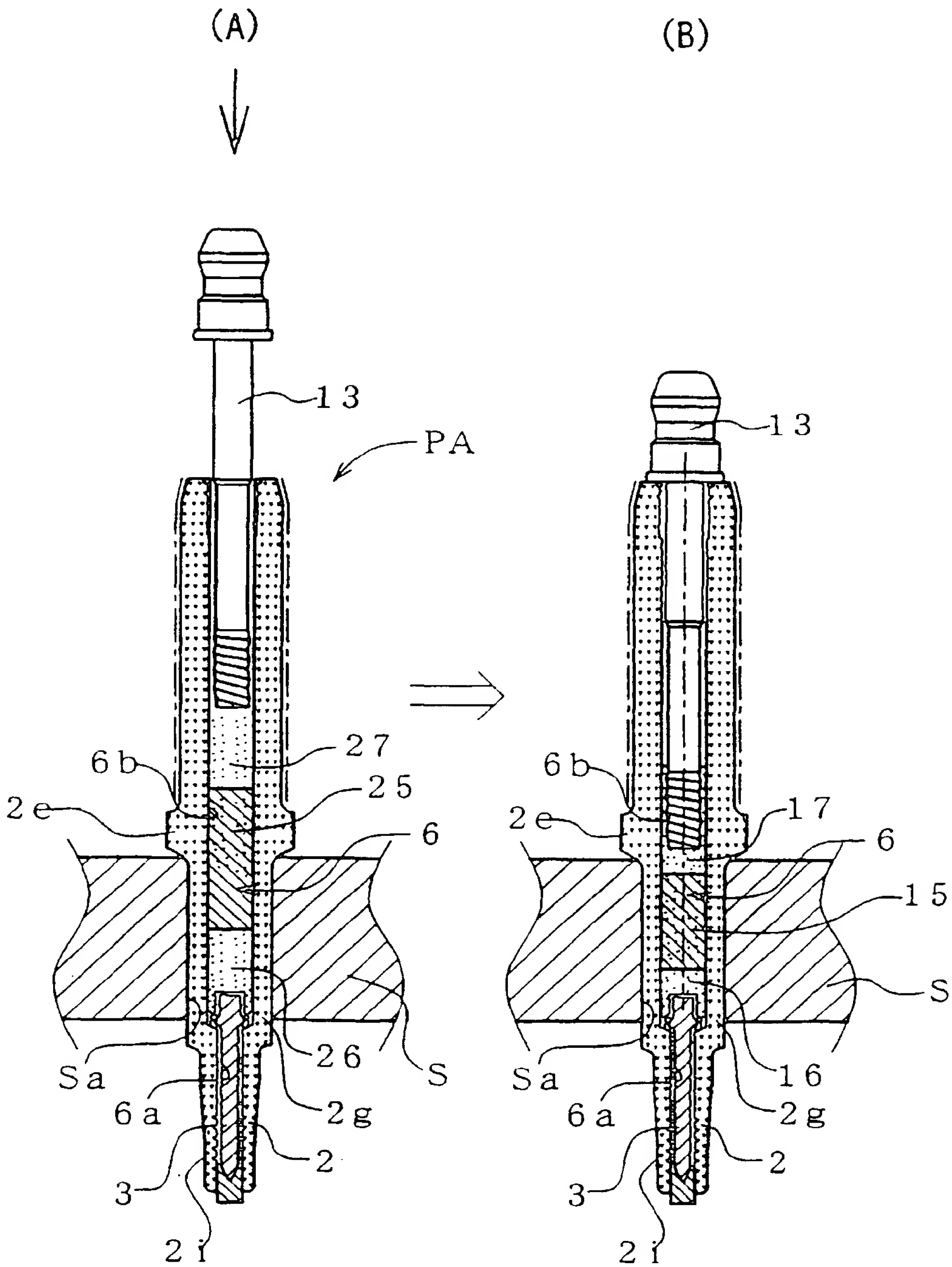

(A)
(B)
13
PA
27
6b
25
2e
6
Sa
26
S
6a
2g
2
3
2i
13
6b
17
2e
6
15
S
Sa
16
6a
2g
2
3
2i

FIG. 7A

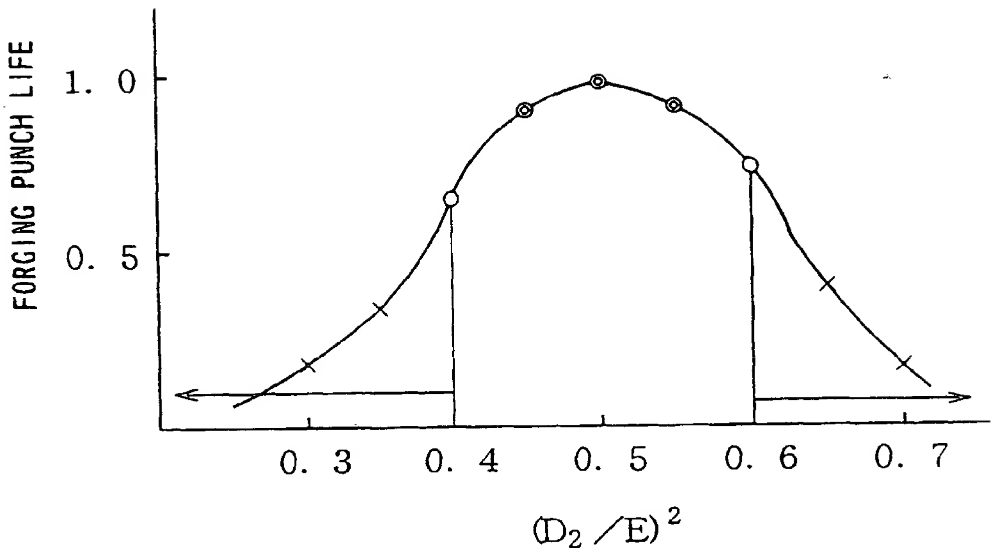

FORGING PUNCH LIFE
1. 0
0. 5
0. 3
0. 4
0. 5
0. 6
0. 7
$(D_2/E)^2$

FIG. 7B

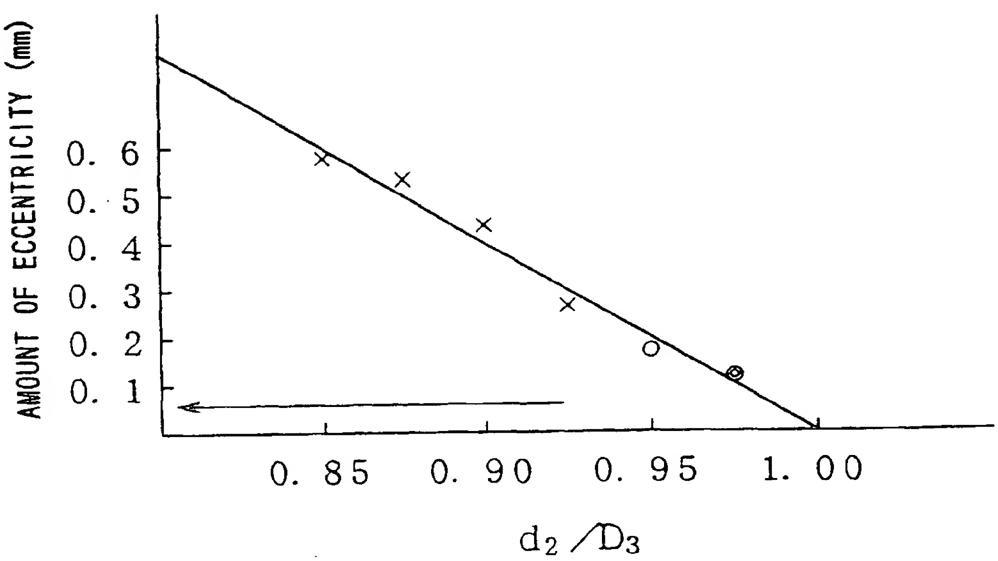

AMOUNT OF ECCENTRICITY (mm)
0. 6
0. 5
0. 4
0. 3
0. 2
0. 1
0. 85
0. 90
0. 95
1. 00
d_2/D_3

FIG. 8

d_2 / d_1	0. 6	0. 65	0. 7	0. 75	0. 8	0. 85	0. 9	0. 95
GLASS SEAL PRODUCTIVITY	○	○	○	○	×	×	×	×

FIG. 9
PRIOR ART